AD-753 356

DEVELOPMENT OF SUSPENSION SYSTEM FOR ARMY FLIGHT PERSONNEL HELMET

Milton D. Smith

Cornell Aeronautical Laboratory, Incorporated

Prepared for:

Quartermaster Research and Development Command

June 1958

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AD-753 356

12-6-11

CORNELL AERONAUTICAL LABORATORY, INC.

REPORT No. OG-1163-D-1

DEVELOPMENT OF SUSPENSION SYSTEMS
for
ARMY FLIGHT PERSONNEL HELMET

Final report, June 1958

Sponsored by
Quartermaster R. & D. Command
Contract No. DA-19-129-QM-910

B U F F A L O, N E W Y O R K

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY

BUFFALO, N. Y.

REPORT No. OG-1163-D-1

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June 1958

Prepared by:* Milton D. Smith
Milton D. Smith

Approved by: Edward R. Dye
Edward R. Dye, Head
Safety Design Research Dept.

* The initial 80% of this contract was under the technical direction of John M. Egly.

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INTRODUCTION

The research and development work reported herein were performed under Contract DA-19-129-QM-910 with the Quartermaster Research and Development Center, Natick, Massachusetts. In abstract, the required efforts as specified in the contract are:

A. Design a suspension system for an Army flight personnel helmet using the combat vehicle crewman shell. The design shall fulfill the following requirements:

1. aircraft crash head protection,
2. compatible with communications system,
3. compatible with cold weather head gear,
4. fit head sizes 6-1/2 to 7-3/4 (two size helmets may be used),
5. meet conditions specified by the Project Officer such as, vision, hearing, compatibility with cockpit, etc.

B. Evaluate designs developed under (A) above by testing models installed in CVC shells. The evaluation shall include assessments of the capabilities to meet the requirements in (A) above.

C. Fabricate not less than five (5) or more than twenty-five (25) helmet suspension types and install in CVC helmet shells supplied by the Government.

OG-1163-D-1

SUMMARY

An Army Flight Helmet was developed and tested. The ballistic shell of the Combat Vehicle Crewman (CVC) Helmet was used as the foundation for the development, and it was outfitted with a suspension system designed as part of the program to provide protection against aircraft crash injury.

A Helmet Impactor was fabricated and was used to evaluate the final design of CVC Flight Helmet. Because of the limited amount of information available in regards to protective requirements for the head, comparative tests were performed with two other military flight helmets. Based on the tests performed, the CVC Flight Helmets can resist double the impact energy tolerable by the other helmets as defined by the protection criteria mentioned in the report.

Five CVC Flight Helmets were fabricated and were forwarded to the Government for additional evaluation.

CONCLUSIONS

A review of data applicable to the evaluation of flight helmets was not conclusive enough to establish absolute head tolerance limits; therefore, tests were made to compare the CVC Flight Helmet with two other military flight helmets. Based on the impact protection criteria defined in the report, the CVC Flight Helmet provides head impact protection superior to the other two military helmets tested.

The Helmet Impactor developed for the testing of helmets was capable of establishing the protective index of the helmets as defined in terms of "bottoming" and head-form acceleration. The thin, instrumented head-form shell is too susceptible to damage during helmet evaluation; therefore, it is not possible to perform a relatively fast and efficient comparison of helmets.

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RECOMMENDATIONS

It is believed that one of the most important protective criteria for flight helmet evaluation is the distribution of the force over the head during impact blows. The instrumented head-form shell was designed to obtain the distribution data. However, it was determined during the testing that it was too fragile for routine comparative helmet evaluations. It is recommended that the instrumented head-form shell b replaced with a head-form capable of withstanding high concentration of impact force without damage while recording the actual force distribution over the surface of the head-form. Several methods of accomplishing this design are feasible. A system of unit pressure segments that actuate relatively rugged strain gage beams might be used. A blanket of unit pressure cells might be applied over a rigid head-form. It is noted that a left-to-right symmetry exists in helmets, making it possible to limit the instrumentation to one side of the head-form.

As the result of a discussion with the Project Officer, it is recommended that additional consideration be given to the attachment methods for the helmet suspension system. Of primary interest is the ease of sizing adjustments to be made by the wearer.

I. FLIGHT HELMET DEVELOPMENT

A. Helmet Design Criteria

During the development of protective headgear, there are many factors that should be considered before the configuration of the headgear is selected. These factors can be divided into categories and their relative importance can be weighted to establish the design standards.

1. Human Factors

   a. visibility
   b. comfort
   c. helmet weight
   d. helmet inertia
   e. ventilation and warmth
   f. communications
   g. noise attenuation

2. Impact Protection

   a. hazard (mass, size, contour, rigidity)
   b. relative impact velocity
   c. energy dissipation
   d. helmet-to-head spacing
   e. helmet shell characteristics
   f. area of coverage required
   g. helmet stability during impact
   h. suspension system characteristics

There are several other items that are sometimes applicable such as secondary use, appearance, etc., that may influence the final design.

To exemplify the influence of helmet application on its design, the present Combat Vehicle Crewman Helmet can be compared with a flight helmet. Both types of helmets have similar Human Factors requirements. However, the requirements differ for Impact Protection.

The CVC Helmet was designed primarily for ballistic protection. A tenacious shell is provided to protect against high velocity - low mass objects. In addition, sufficient rigidity is provided in the shell to protect the head from bumps against surfaces and objects in combat vehicles. The function of the suspension system is to provide the proper ballistic spacing

in the helmet and to maintain helmet stability during the activities of the wearer.

In a flight helmet, entirely different impact-resistant characteristics are required. The helmet should be designed for relatively high mass - low velocity impacts. The shell should be rigid to prevent local deformation during high energy blows. The suspension system should absorb as much energy as practical with as uniform a force distribution over the head as possible. The helmet-to-head spacing should be as large as possible without introducing objectionable helmet inertia.

In the work that was performed under this contract, the CVC helmet shell was to be used as the basic structure for a flight helmet and a suspension system was to be incorporated that would fulfill the requirements of a flight helmet as well as a ballistic helmet. An extensive amount of effort has already gone into the design and development of the CVC shell. Problems such as ballistic resistance, field of vision, area of head coverage, helmet inertia, helmet-to-head spacing, and noise attenuation have all been considered and an acceptable ballistic shell has been developed. Since all of these items are compatible with flight helmet design, the CVC shell provides a good foundation for the development of a flight helmet that exhibits ballistic properties.

There are two major problems that confront the designer of a flight helmet:

1. The magnitude of the blow that can be directed to the protected head.

2. The tolerance of the human head to irreversible injury.

It is nearly impossible to predict the actual impact energy that the protected head will encounter during an airplane crash. There are several factors that can be considered to provide additional information; however, the exact magnitude of the blow cannot be firmly defined.

For a particular aircraft, there are design standards that can be applied. The aircraft has compartment and seat attachment structural design limits. Dependent upon the size and type of aircraft these vary between 5 and 40G. If the deceleration of the aircraft exceeds the design value, the destruction of the compartment and the added mass of the seat and possibly armor plate practically eliminates the chance of survival of the occupant. Therefore, these values can be used as arbitrary protective limits for the crash deceleration of the aircraft. The proximity of the protected head to the various hazards in the compartment is reasonably

well defined for occupants of aircraft. This distance is relatively small and usually is approximately one to three feet. By assuming a uniform deceleration at or below the level of the compartment design limit for the aircraft and an absolute velocity equal to the initial aircraft velocity for the head, it is possible to determine the relative velocity between the protected head and the hazards of the compartment if the distance between the head and the hazard is known.

Having determined the relative velocity between the head and the compartment, it is necessary to establish a representative mass for the head to estimate the impact energy or the magnitude of the blow. Studies performed at the Laboratory in conjunction with automotive safety work have provided information as to the per cent of body mass that acts through the head for various body attitudes and various angles of impact surface-to-flight path of the head. The data are summarized in Reference 47. For a seated person, as in aircraft, the percentage of body mass that acts through the head during impact varies between 7% and 27%, or for a 200-pound person the total effective mass contributing to the blow on the head would be 14 to 54 pounds.

From this type of analysis, it is noted that the minimum energy that will be delivered to the head during a critical airplane crash is in the magnitude of hundreds of foot-pounds. Since the unprotected head can withstand impact energy levels of approximately 50 foot-pounds against flat surfaces without skull fracture, it is necessary to provide a protective headgear that will efficiently bridge the gap of energy-level difference. The helmet, itself, because of its limited helmet-to-head spacing (3/4-inch), can not do much in absorbing large energy differentials. However, it can be designed to distribute the force of the impact over the head to appreciably higher energy levels. There is evidence in Reference 1 of the increase in fracture limit that can be achieved by proper distribution of force over the head. Fluid-filled plastic shells were developed to simulate impact strength characteristics of the human skull. It was found that a properly designed energy-absorbing structure which basically provided relatively uniform distribution of force over the surface of the plastic skull provided impact protection at energy levels twenty-five times greater than was permissible against a hard, flat, unprotected surface.

The other problem that confronts the helmet designer is the tolerance limits of the human head that should be used for flight helmet design and evaluation. An appreciable amount of work has been done in the field and many of the reports have been listed in the Bibliography. Much of the information is directed toward the medical aspects of head injury; however, some can be applied to an engineering analysis. A summary of the applicable information is as follows:

1. Energy tolerance of the human head against a hard, flat surface, 400 to 1200 inch-pounds, average 600 inch-pounds. - results from cadaver tests.

2. 60G deceleration of the head can be tolerated. - based on human tests.

3. 200G deceleration of the head can be tolerated - calculated for persons falling from high places without severe injury.

4. Rate of change of deceleration of 1200 G/sec. can be tolerated - based on human tests (over comparatively long periods of time).

5. Rate of change of deceleration of 20,000 G/sec. can be tolerated - based on statistical data from New York State Boxing Ring Platform (over comparatively short periods of time as during impact).

Of these various controls that are applicable to an engineering analysis, the limit of 600 inch-pounds, or 50 foot-pounds, is of primary concern because it is so far from the anticipated impact energy. The limit of 600 inch-pounds is based on impact against a solid flat surface; therefore, the helmet should be designed to prevent concentration of force on the head and the force should be distributed as much as possible. In this manner, the level for skull fracture will be raised. The suspension system can provide the distribution until the helmet shell bottoms against the head; therefore, the suspension should be relatively stiff to prevent this occurrence. Since the major problem confronting the helmet designer is the survival of the wearer, the stiffness of the suspension should be dictated by the highest deceleration that the head can tolerate. From the evidence available at this time, 200 G has been taken as this limit because "bottoming" of the helmet against the head will produce a critical situation, and any method of preventing force concentration without exceeding the other limits or controls will provide a desirable flight helmet.

B. Helmet Design

Many of the factors that normally would require consideration in the design of a flight helmet were already established by the selection of the Combat Vehicle Crewman Shell as the foundation for the helmet. However, it was necessary to consider other aspects in the design. It was necessary to maintain the helmet-to-head spacing of the conventional CVC helmet because of ballistic requirements. It was necessary to prevent "bottoming" of the helmet under relatively high-energy level impacts. The suspension system was to be of such a design as to accept the communications equipment and provide good helmet stability. The helmet has to provide impact protection from any direction of blow.

Early in the design of improved headgear it was found that the greatest weakness of the helmet shell existed in the rim direction. To arrive at comparative static data, force-deformation plates were made of several helmets in Figure 1. The helmet denoted CAL Football incorporated a composite pad that acted as both a beam and a pad. The other helmets included their standard strap suspensions. It is realized that the CAL helmet may be over-designed and, since the F/d of the CVC shell falls toward the CAL F/d, it was believed that the CVC shell had adequate stiffness to proceed with the helmet design and dynamic evaluation.

Various methods were considered for the suspension system in the helmet, and the final design consisted of three components: the front head band, back head band with nape strap, and a geodetic crown suspension. The system was compatible with the sizing problem and provided good stability of the helmet. The medium CVC shell was outfitted to size from 6-1/2 to 7-1/8 and the large CVC shell was outfitted to size from 7-1/8 to 7-3/4.

The front head band consists of a tension strap tied to each side of the helmet with a compression pad of plastic foam between the strap and the helmet shell and a sizing pad of plastic foam between the strap and the head. The entire assembly is encased in soft leather. Under a frontal impact the tension band carries a distributed force to the head and the compressive pad softens the contact of the shell against the head if "bottoming" should occur.

The back head band is a nape strap that acts as a tension band with sizing adjustment, and it performs in a manner similar to the front head band. Plastic foam bumper pads are mounted on the helmet shell under the tension strap to attenuate any "bottoming" that might occur to the back of the head. A nape strap saddle and loop are also included in the back to assure proper positioning and stability of the helmet during normal activity.

The Geodetic Suspension is a patented system of arranging straps to provide good distribution of forces from the helmet to the head. A detailed description of this arrangement can be found in Reference 48. Normally, four straps are used and are attached to the helmet at eight equidistant points around the periphery. A more important characteristic of the suspension is that the straps are spread over the top of the head and do not concentrate their bearing load. The system as used in this helmet differs from the original method by doubling the straps in each helmet attachment to reduce the amount of adjustment for the wearer. However, the general characteristics of the strapping over the head are maintained. A piece of soft leather was used as the crown of the suspension to maintain the spacing of the straps and provide comfort for the wearer. Relatively nonelastic straps were selected to delay "bottoming" of the helmet, and

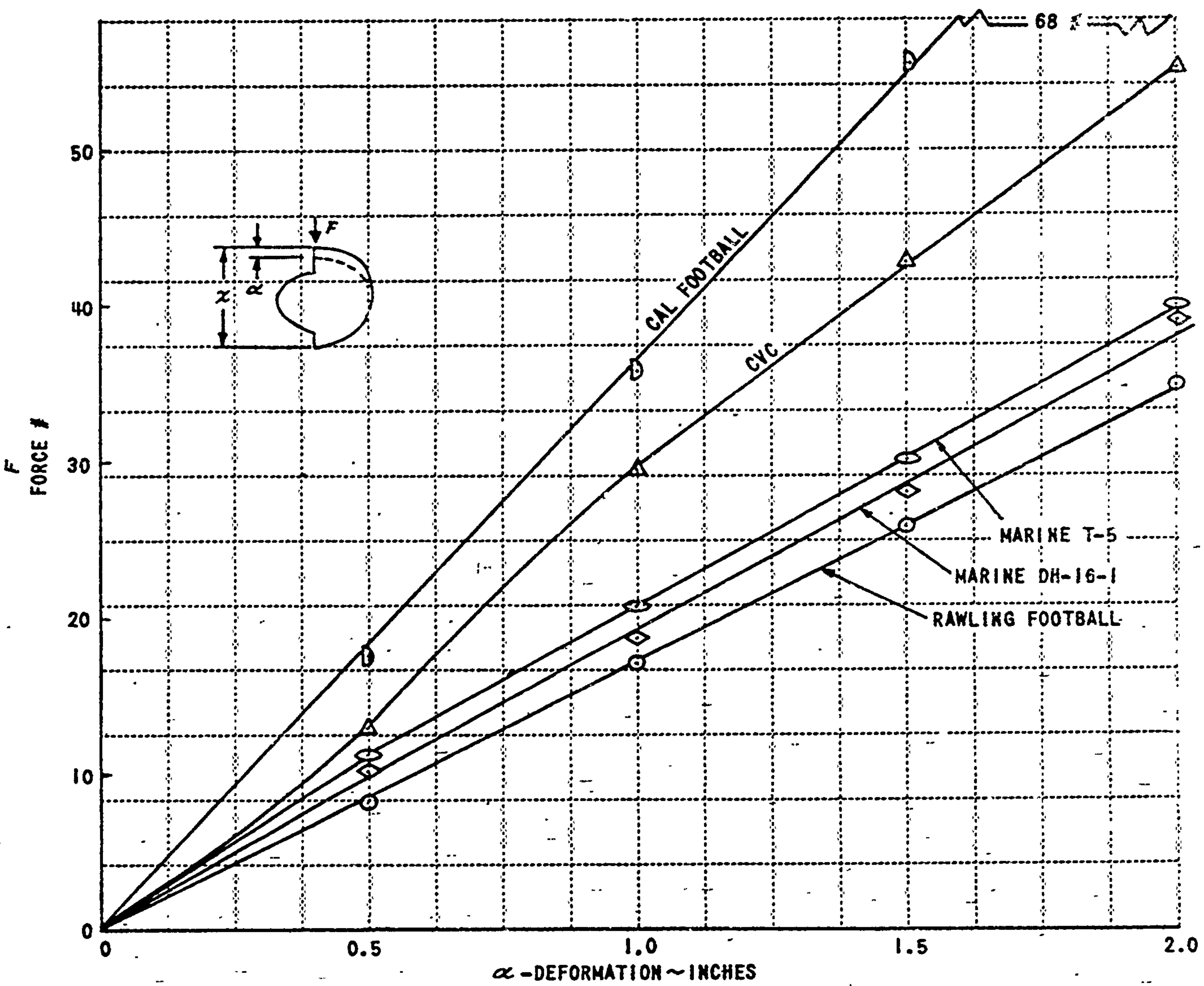


Figure 1 HELMET SHELL-RIM STIFFNESS TEST RESULTS

provide a high level of protection. In addition to the geodetic strap suspension, a one-quarter inch layer of plastic foam used by the Government in the crown of the CVC helmet shell for sound attenuation was also considered part of the energy absorption system. Since the straps and the leather have very little cushioning effect if the helmet "bottoms" on the head due to high-energy impacts, the layer of plastic foam provides a cushion to attenuate the slap of the helmet against the head at the end of an impact blow. In addition to the three parts of the suspension system, the padded earphones assist in absorbing side blow energy and also assist in the stability of the helmet. Drawings of the suspension system are shown in Figures 2, 3, 4, and 5, and an assembly photo is shown in Figure 6. In addition to the suspension system drawings, Figures 7 and 8 show the spacing between the helmet and head.

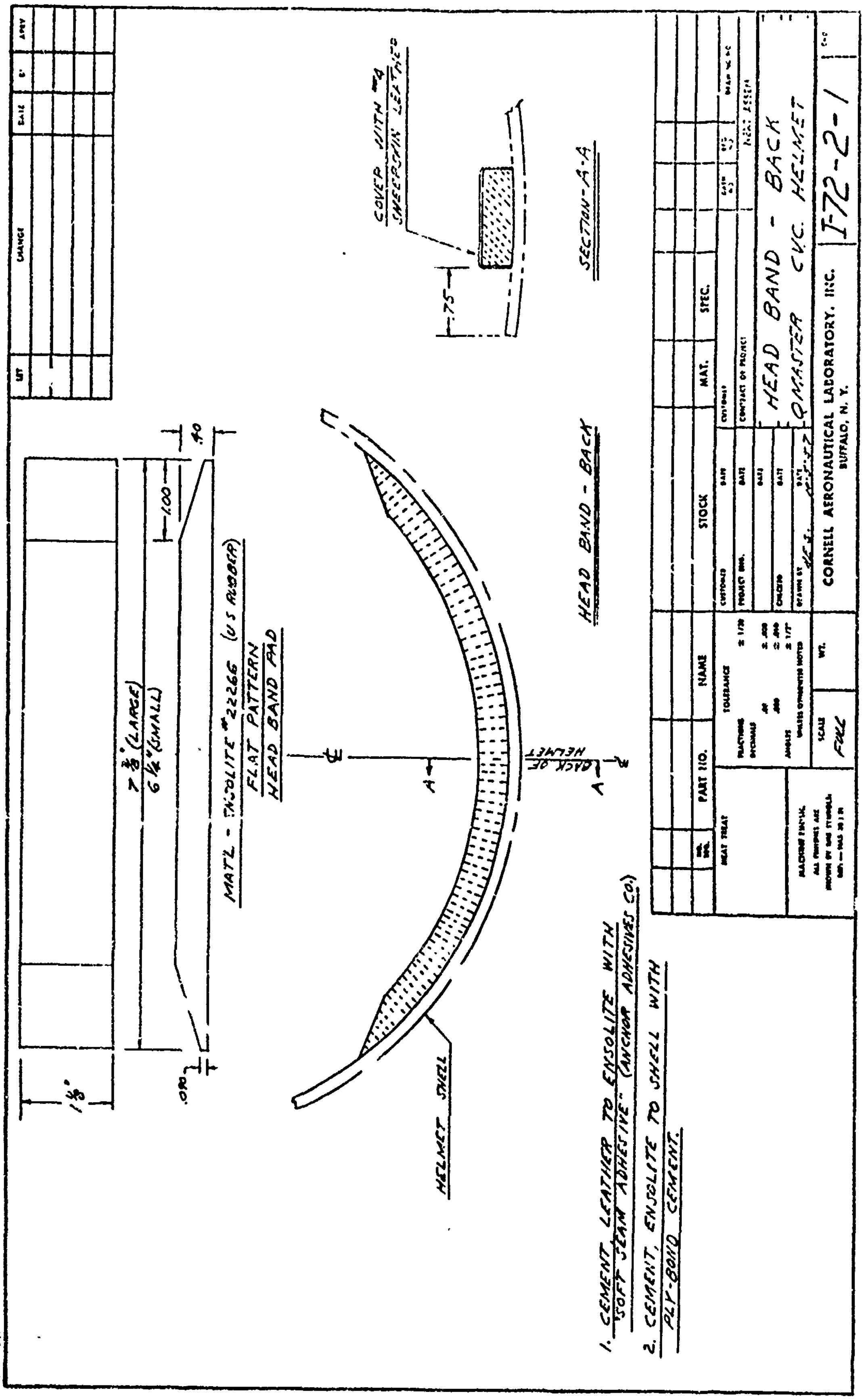


Figure 2

OG-1163-D-1

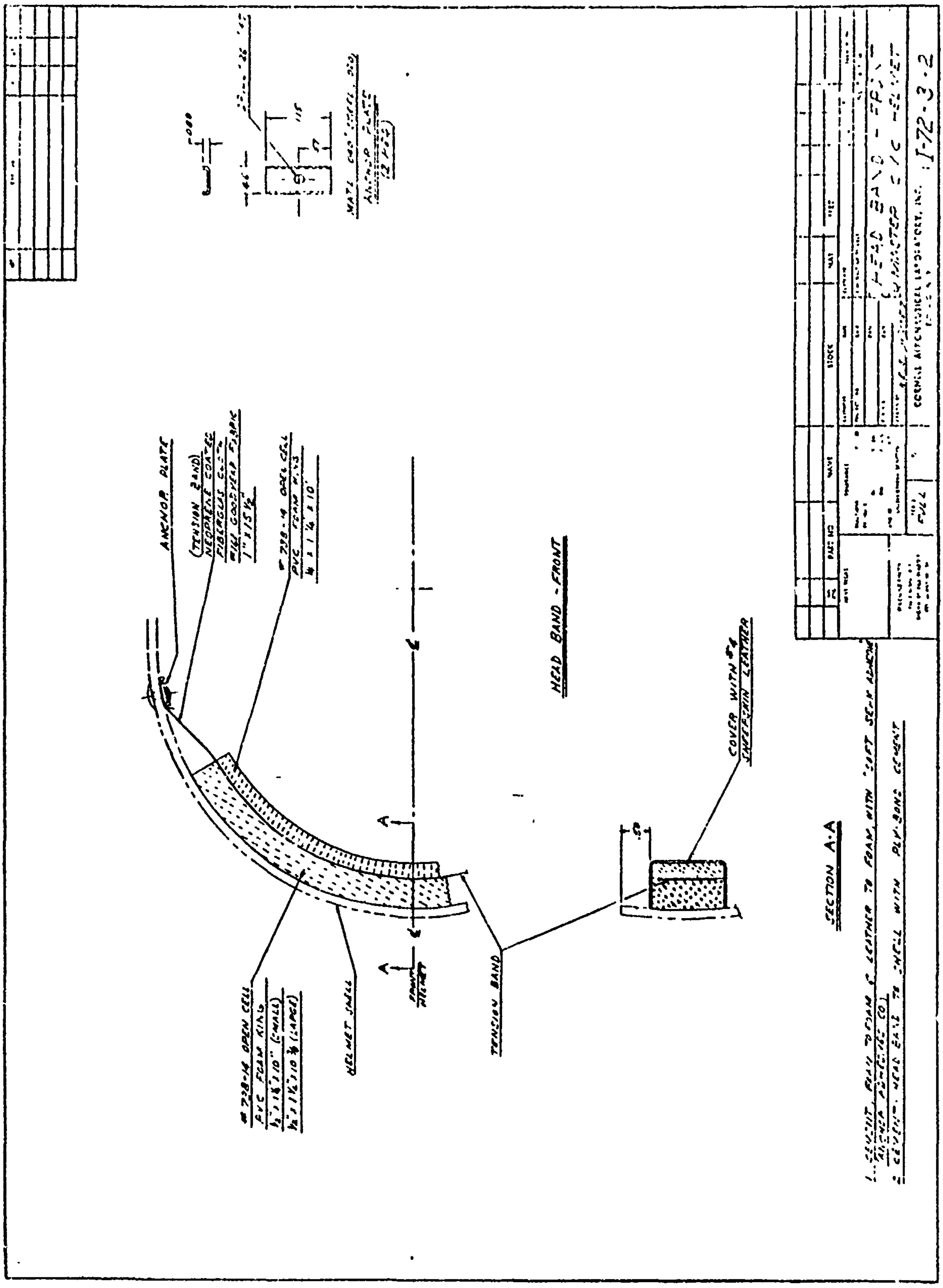

ANCHOR PLATE
HEAD BAND - FRONT
COVER WITH #4 SHEEPSKIN LEATHER
HELMET SHELL
TENSION BAND
SECTION A-A

Figure 3

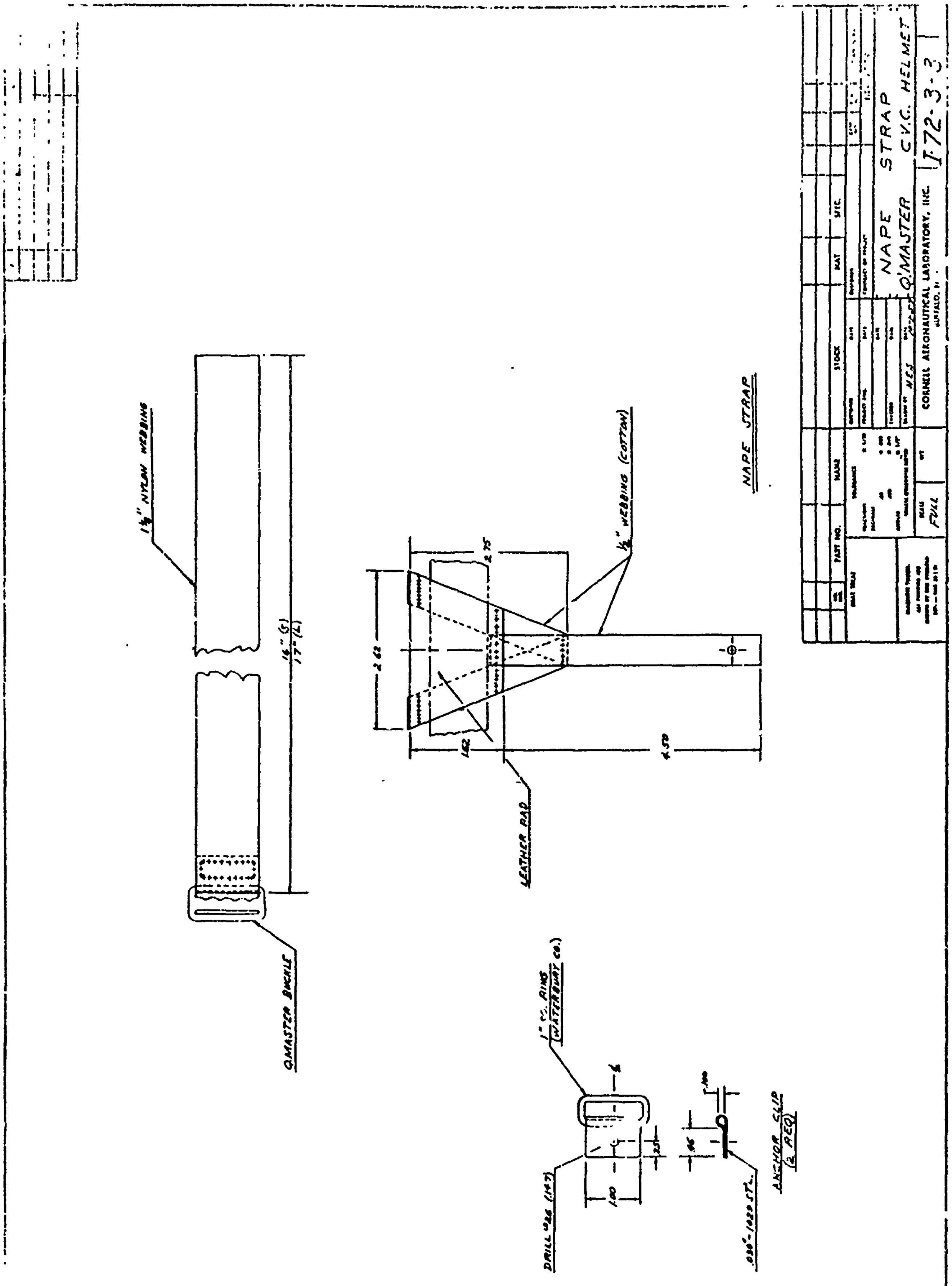


Figure 4

OG-1163-D-1

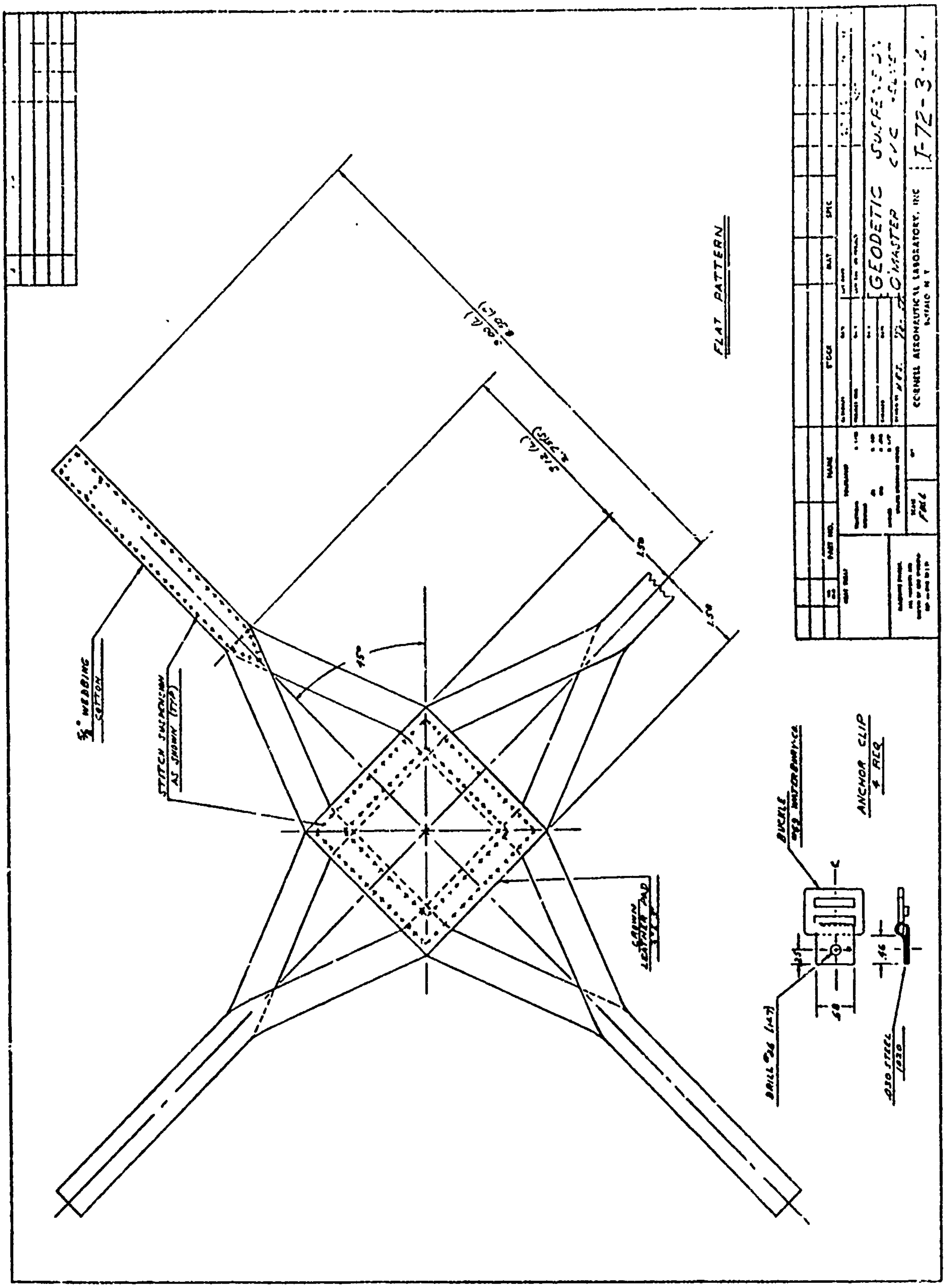

FLAT PATTERN
ANCHOR CLIP
4 REQ
BUCKLE
STITCH SUSPENSION AS SHOWN (TYP)
45°
GEODETIC
CORNELL AERONAUTICAL LABORATORY, INC
BUFFALO N Y
I-72-3-2

Figure 5

Figure 6 INSIDE VIEW OF C.V.C. HELMET SHOWING INSTALLATION OF C.A.L. FLIGHT SUSPENSION SYSTEM

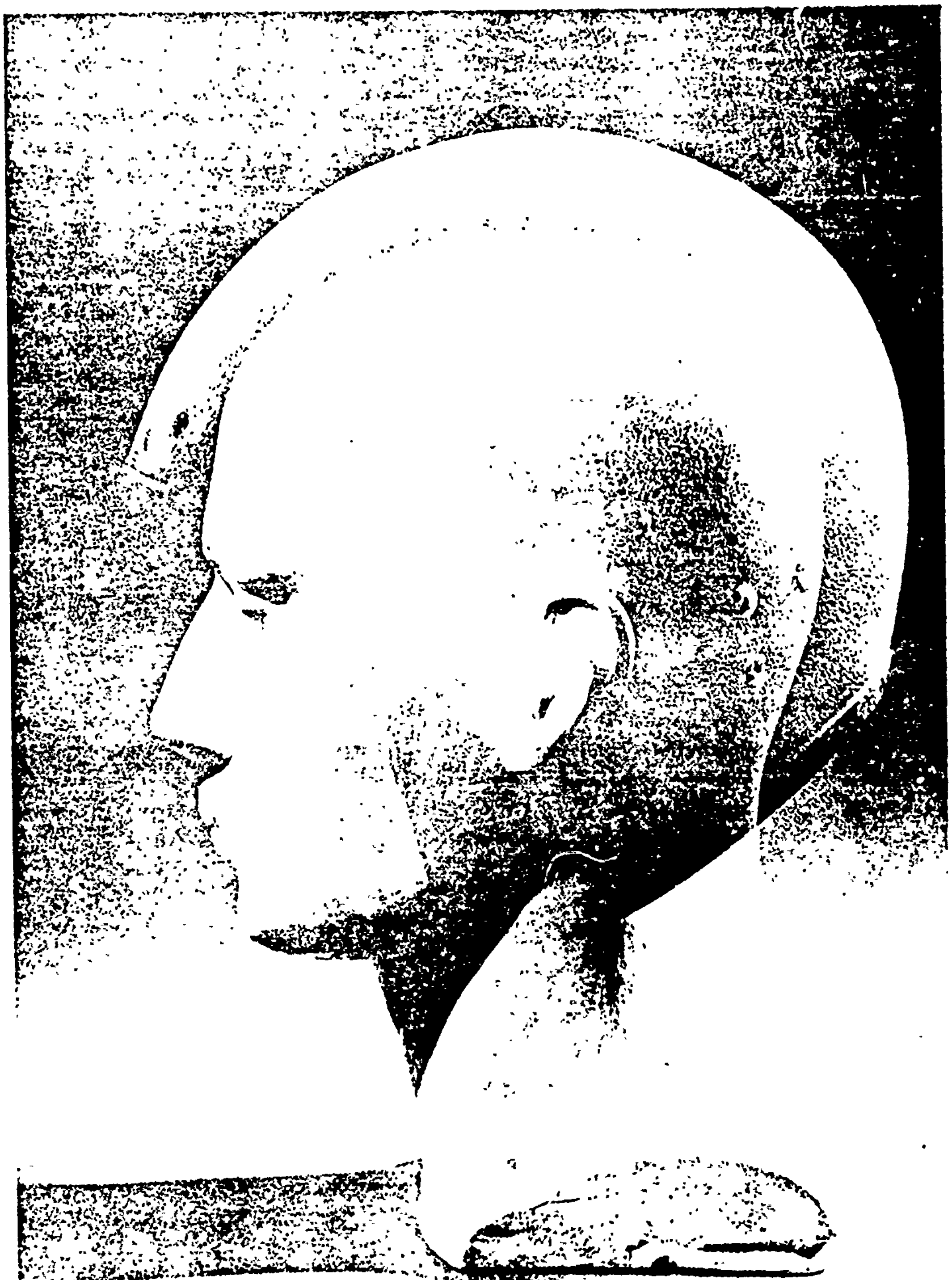


Figure 7 SIDE VIEW-DOUBLE EXPOSURE SHOWING HEAD TO HELMET SPACING OF C.V.C. HELMET WITH C.A.L. FLIGHT SUSPENSION SYSTEM

Figure 8 FRONT VIEW-DOUBLE EXPOSURE SHOWING HEAD TO HELMET SPACING OF C.V.C. HELMET WITH C.A.L. FLIGHT SUSPENSION SYSTEM

II. FLIGHT HELMET EVALUATION

A. Development of the Helmet Impactor

Many types of flight helmets are presently in use, and it would be extremely difficult to determine the efficiency with which the helmets perform the task for which they were designed. The difficulty has arisen because there are no absolute values that can be chosen to establish standards of evaluation. It was noted under the Helmet Design Criteria section of this report that the impact blow can have energy levels of hundreds of foot-pounds and greater, and that information has been obtained as to the acceptable impact tolerances of the human head. It is recognized that the impact energies can produce injury potentials far in excess of the limited energy absorption capabilities of the helmet - head combination; therefore, the impact tolerance of the protected head must be improved if the wearer is to survive. Since a flight helmet may be the key to survival, the efficiency with which the helmet protects the head under impact blows should be defined.

As one part of this program, an evaluation of the CVC helmet with flight suspension was to be made. Therefore, it was necessary to provide a method for carrying out the evaluation. The various factors that can be applied to the helmet evaluation problem were reviewed and a list of test requirements were established.

1. Testing should be dynamic instead of static to more closely simulate actual application.

2. Body inertia and neck flexibility attachment should be simulated.

3. The helmet mounting head-form should approximate the shape and size of the human head.

4. The magnitude of the blow should be variable and of sufficient level to exceed the normal energy-absorbing capabilities of the helmet.

5. The direction of impact should be adjustable to encompass as much of the helmet as possible.

6. The peak deceleration of the head should be measured during the impact.

7. A measure of pressure concentration or force distribution over the head-form should be made during impact.

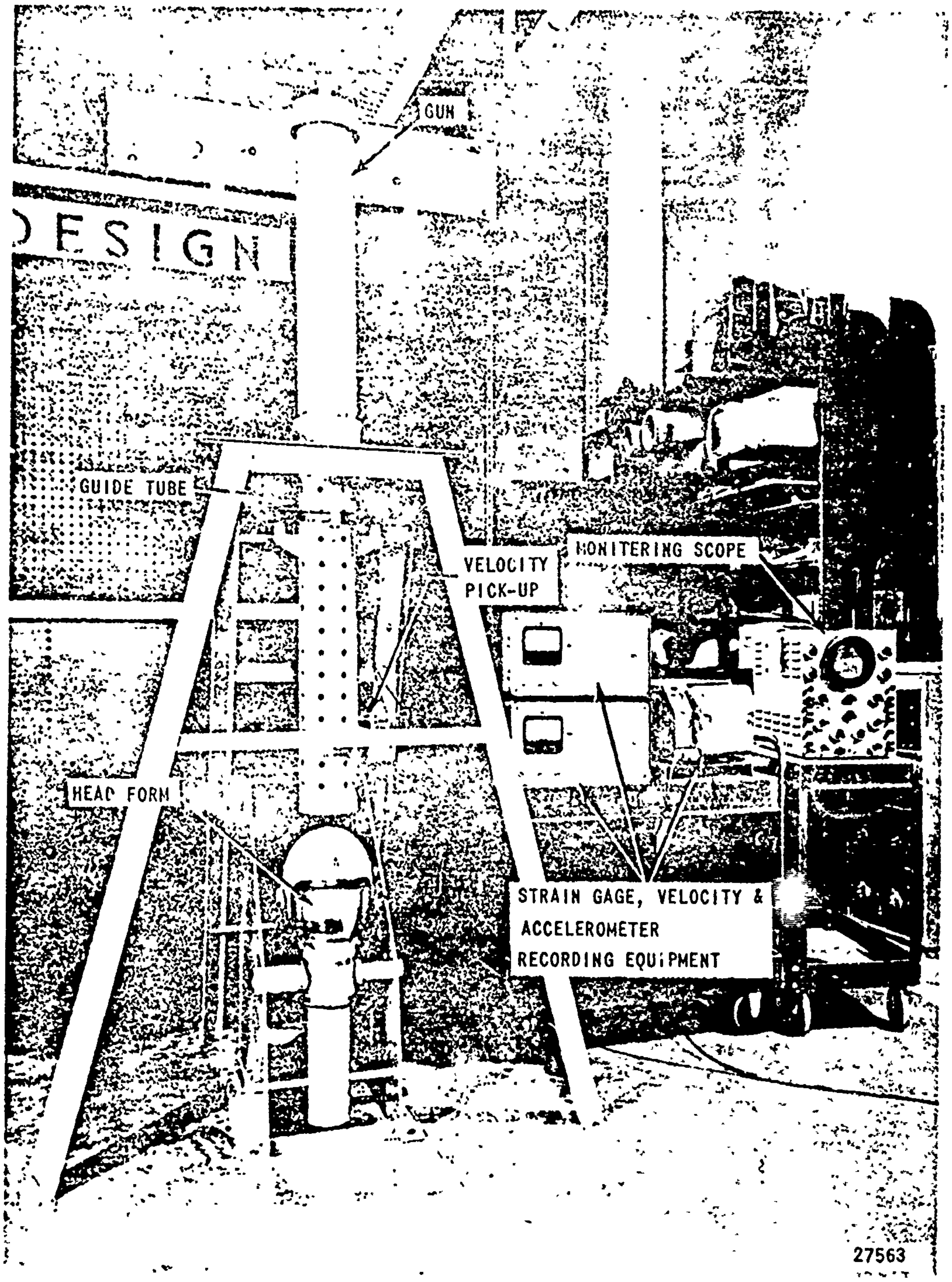
8. Comparative data should be obtained because there are no absolute values that can be applied to the data obtained.

A device to test helmets, designated "helmet impactor", was developed.

The equipment is shown in Figure 9. The main apparatus, the impactor, consists of a gun, guide tube, and supporting structure. The gun is mechanically operated using a compression spring for the driving force. The guide tube includes the latching and trigger mechanism and the tube is designed so as to restrain the projected missile from ricocheting off the helmet. Figure 10 shows the head-form without a helmet, details of the head-form support and the striker. The head-form crown is a hollow aluminum (24ST) shell resting on a cast aluminum base. This, in turn, is fastened to a semi-flexible neck piece fashioned from high pressure fire hose. This assembly is designed to permit horizontal, vertical and intermediate angular hits. In all but the vertical position, two conditions of impact can be simulated - fixed and free swinging. See Figure 13. The lower portion of the head-form assembly is weighted to simulate the mass of the upper human torso (approximate weight - 30#).

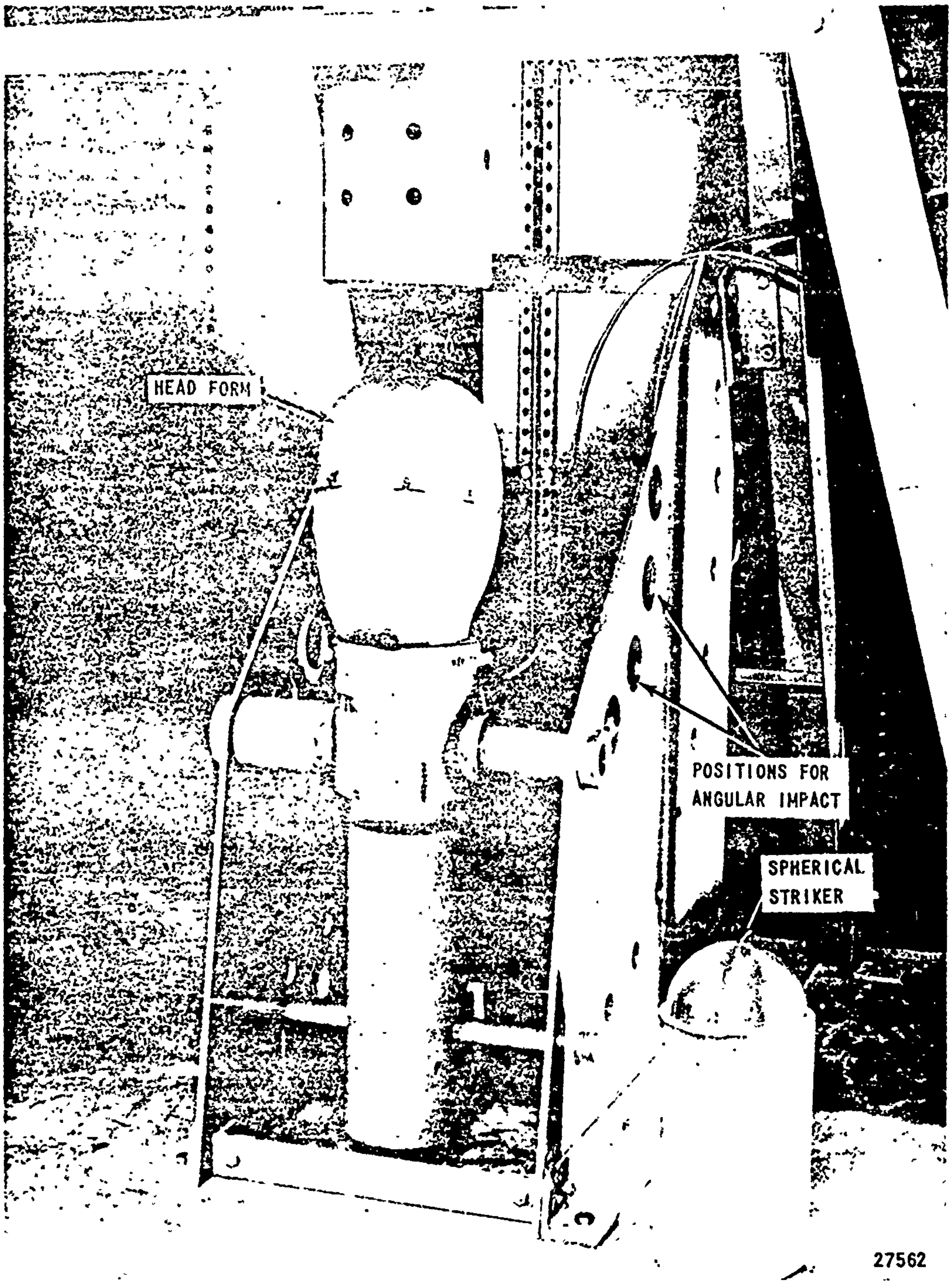
The head-form contains instrumentation which will provide data for comparative evaluation of one helmet to another. This instrumentation is shown in Figures 11 and 12. Two accelerometers are located in a position that will be in line with the impact blow. One will measure horizontal accelerations, the other, vertical accelerations. The resultant measurements can be vectored to indicate the acceleration direction of the head. The mount for the accelerometers can be rotated to accept acceleration measurements for a side blow. Strain gages are affixed to the head-form shell to permit indication of force-distribution over the shell. Also, a gage is located directly under the impact point, the resultant reading providing an indication of "bottoming". Initially, strain gages were affixed to the head-form shell at the quadrant points near the lower edge. In theory, the strain near the edge periphery is a function of both the magnitude and the distribution of the force reaching the head-form.

Some initial impact tests were performed using the CVC helmet with the prototype suspension system, a Gentexite helmet and a P-3, P-4 helmet. The latter two helmets are production protective flight helmets. During this series of tests, the instrumented head-form did not provide desired results. The problem was analyzed and it was determined that the strain gages located around the base of the head-form shell were not indicating the variation in distribution of load over the top of the head-form. Several tests were performed by varying the area of force distribution and there was very little change in the indication. It appeared that reactions between the head shell and the base during impact prevented the system from operating properly. Strain gages were placed at the minimum radius of curvature of the head shell (approximately mid-way between the crown and

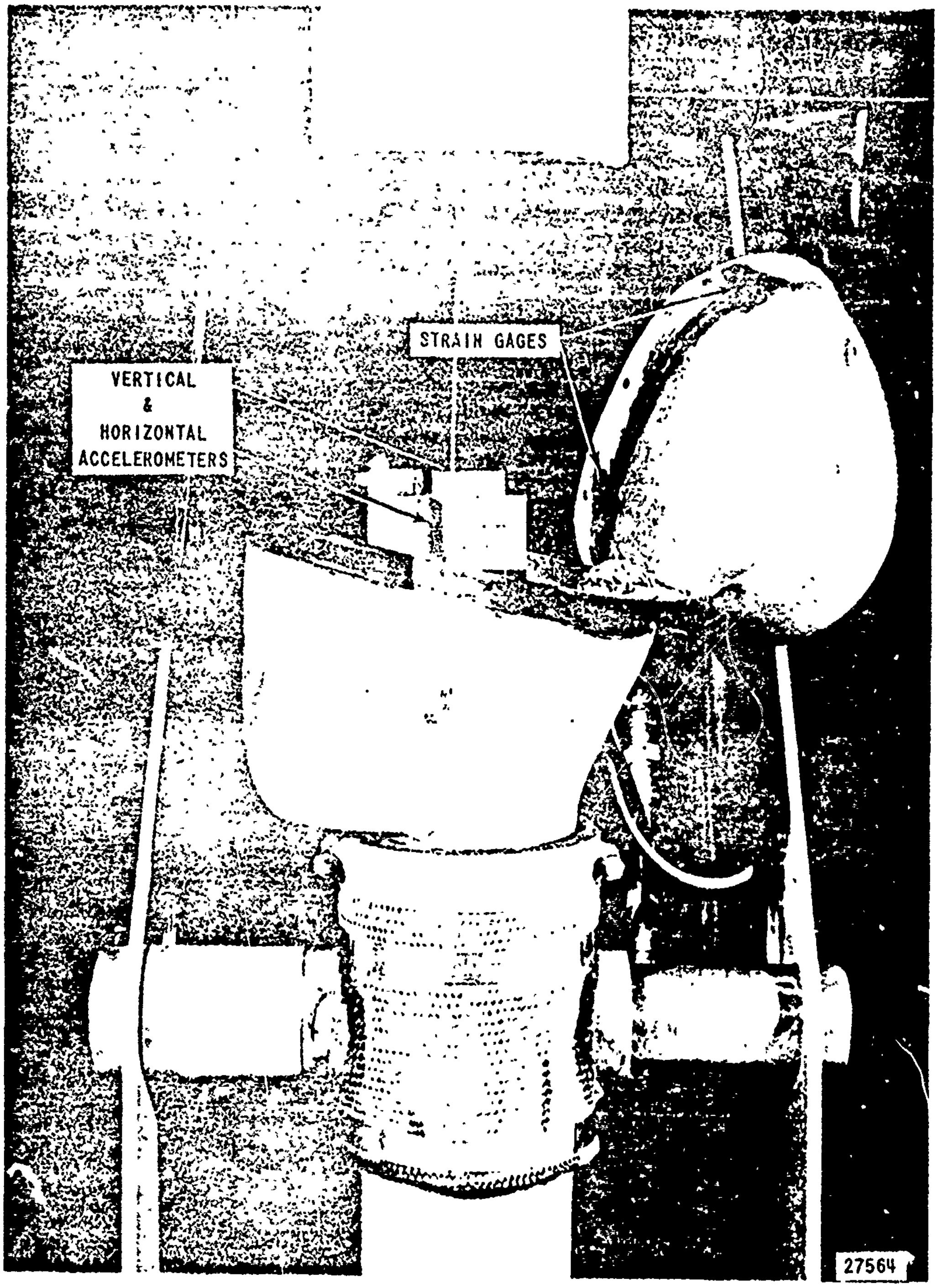


HELMET IMPACTOR

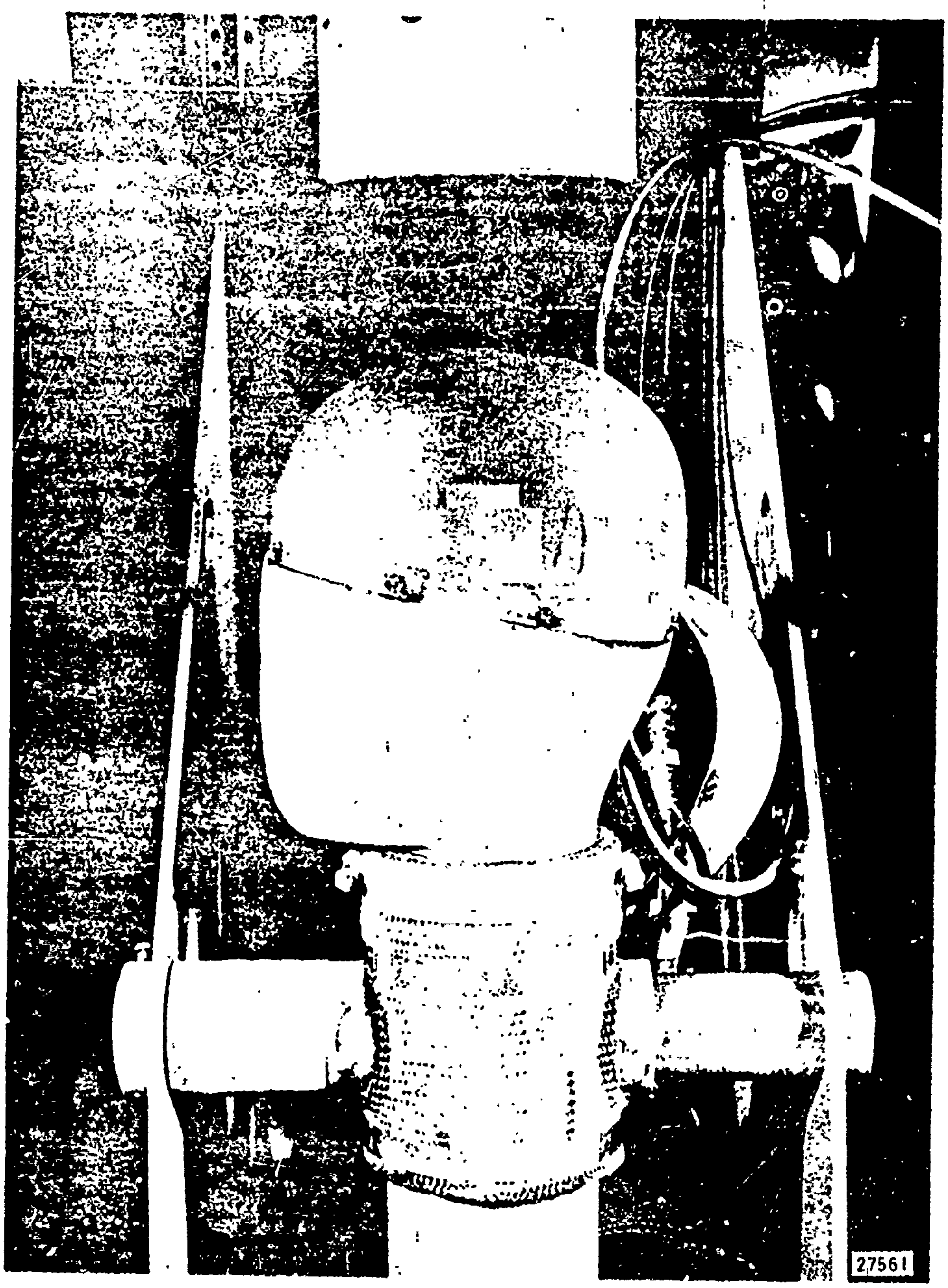
Figure 9



HELMET IMPACTOR
HEAD FORM & STRIKER
Figure 10



HELMET IMPACTOR
HEADFORM INSTRUMENTATION
(HEAD ROTATED 90°)
Figure 11



HELMET IMPACTOR
DOUBLE EXPOSURE OF
HEAD FORM
(HEAD ROTATED 90°)

Figure 12

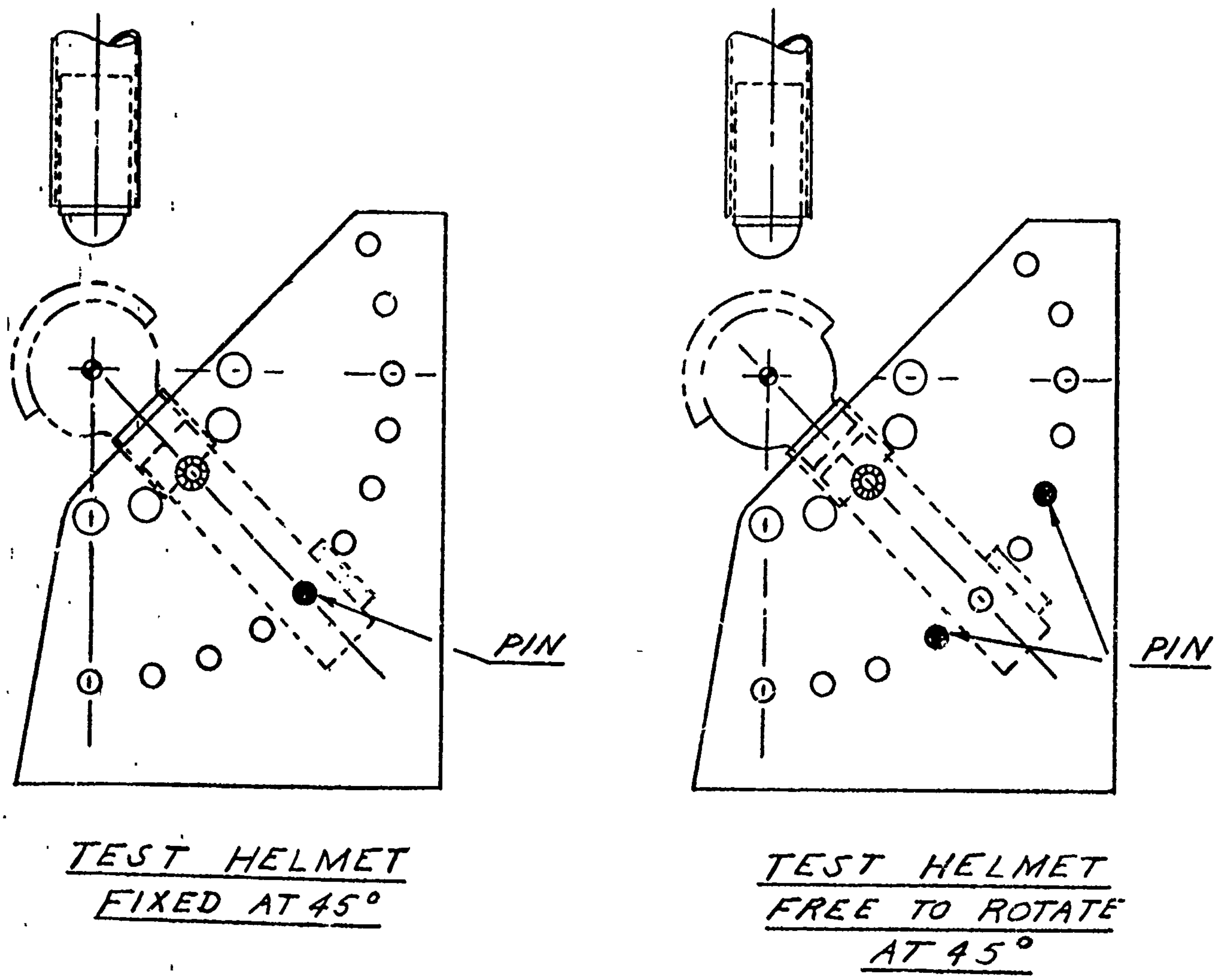

PIN
PIN
TEST HELMET
FIXED AT 45°
TEST HELMET
FREE TO ROTATE
AT 45°

Figure 13

the base of the shell). The gages were located on the front and back and on both sides as well as directly on the crown of the head-form shell. In this manner, the mounting structure of the shell to the head-form base does not influence the measuring system. Distribution of load is determined by the strain produced in bending of the head-form shell. For a given force, higher strains will be obtained from concentrated loads than from uniformly distributed loads. This is similar to the strain characteristics of simple beams in bending. Static and dynamic distribution tests were performed using this measurement system and improved results were obtained.

Calibration tests of the helmet impactor were completed. The range of impact velocities that can be applied to helmets is 10-40 ft./sec. When the 9-pound striker is used, this velocity range provides impact energies of 170 to 2700 inch-pounds which include the values normally used for comparative evaluation of protective headgear.

All signals were recorded by oscillograph at a paper speed of 32 inches/sec. The strain gage and accelerometer signals were amplified by carrier-type amplifiers with a frequency response of 500 cycles/sec. The strain gage data were reduced to values of strain in the aluminum shell in microinches per inch to provide a common reference for all data. The conventional method of gage shunting was used to calibrate the individual gages (SR-4, A-7) and the 200G accelerometers (Statham A5A-350-200) were calibrated from data supplied by the manufacturers (Statham Laboratories, Inc.). Impact velocity measurements were obtained by mounting an electromagnetic pickup in the guide tube. As the front edge of the striker passed the pickup, a voltage spike was generated and as the rear edge of the striker passed another spike was generated. The signal was introduced to a galvanometer of the oscillograph and velocity could be determined from the length of the striker and the time between the spikes recorded on the oscillograph.

An approximate relationship between the number of turns applied to the propulsion spring and impact velocity has been presented in Figure 14. Normally, this is used to establish a test condition and the actual velocity of impact is measured during each test.

For blows to the helmet from various angles it is necessary to orient the accelerometers in the plane of the blow. To accomplish the adjustment the head-form base is removed from the fire hose attachment and a screwdriver adjustment in the head-form base rotates the accelerometer assembly.

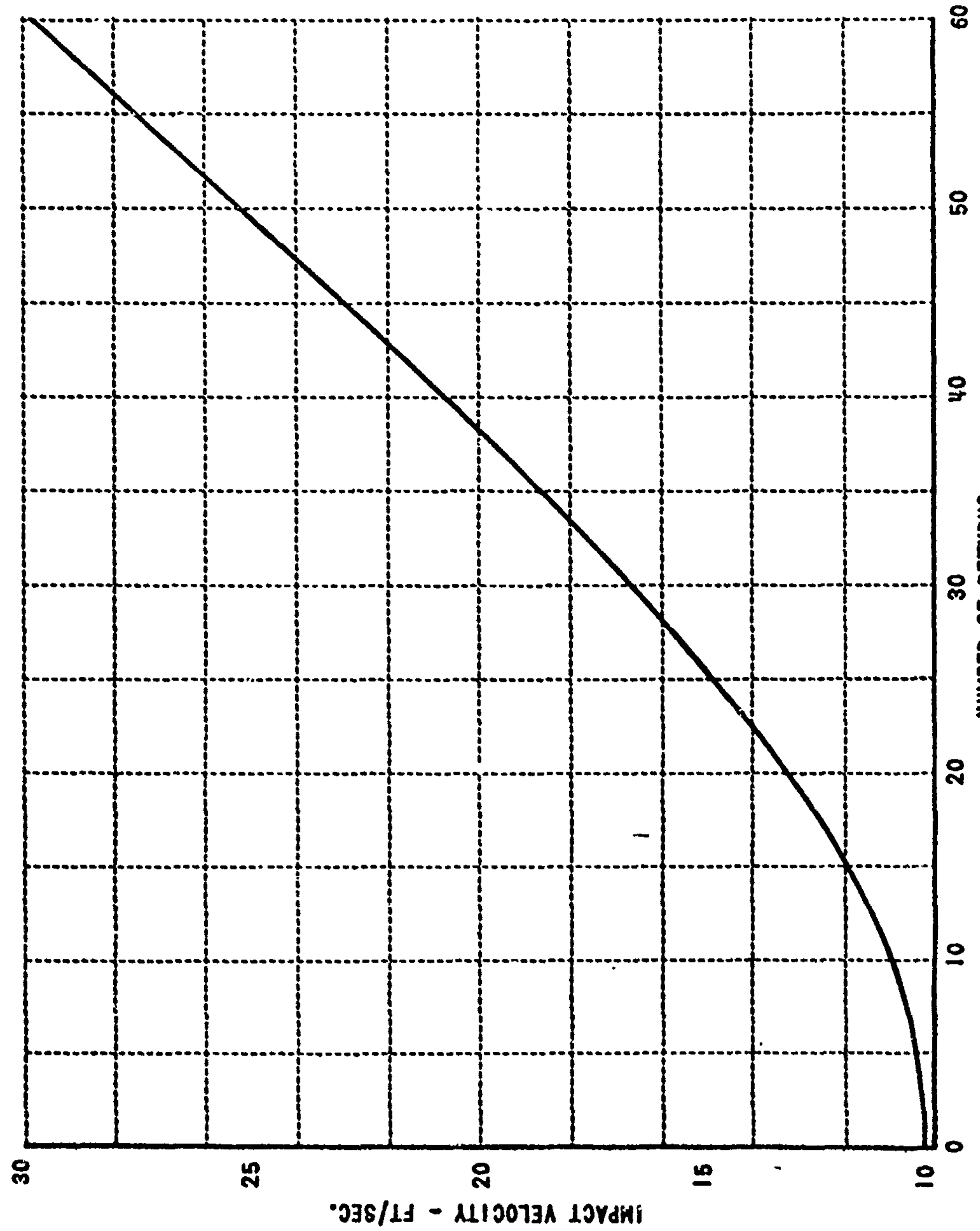


Figure 14 APPROXIMATE CALIBRATION VELOCITY vs TURNS HELMET IMPACTOR
FOR 9 POUND STRIKER

B. Dynamic Helmet Evaluation

The testing of the CVC Flight Helmet was performed with the Helmet Impactor developed during this program. To obtain an evaluation of the helmet, it was necessary to obtain existing helmets for dynamic comparison because absolute measurement of the helmet protective qualities cannot be defined. The Government furnished two military flight helmets to be used for the comparative evaluation. The helmets were designated by the Government as Gentexite and P-3, P-4, and were of different basic construction. The Gentexite Helmet has a ribbed shell with a foam cushion spacing the helmet from the head. The P-3, P-4 Helmet has a relatively rigid shell and has a suspension system of straps and lacing for positioning the helmet on the head. Both helmets are protective flight helmets but they do not have ballistic properties.

An experimental suspension system was installed in a CVC shell to obtain information for a prototype design that would fulfill the requirements of the contract. The original helmet components were selected based on knowledge gained in the development of headgear under government and commercial programs, and the selection was augmented by tests where applicable. During initial dynamic testing, progressive modifications were made to the CVC flight suspension system to improve its protective qualities.

Comparative tests of the three helmets (CVC Flight, Gentexite, and P-3, P-4) were made with the Helmet Impactor. In one instance a CAL-designed football helmet was tested to obtain additional information about the geodetic type suspension system. This helmet was also selected because during its use in the last five years at Cornell University, football players using this type of helmet have received no head injuries.

Two basic measurements were obtained during the evaluation; the peak horizontal and vertical components of the acceleration of the head-form and an index of the strain distribution in the instrumented head-form. Impact velocities were increased until one of these controls indicated that head injury could be expected with the particular helmet being tested. The magnitude of the blow that can be delivered to the helmet during a crash is more or less indeterminate. Also, it is difficult to anticipate the direction from which the blow will be delivered. To cover the range of energy and direction, the impact energy was gradually increased and the direction of impact was varied to investigate the full effectiveness of the helmet. Each helmet will be discussed individually to point out its protective qualities.

Gentexite Helmet

This helmet should be relatively comfortable and should respond well to the buffeting blows associated with high speed aircraft. However, during the tests performed with the Helmet Impactor, the helmet did not provide impact protection comparable with the CVC-CAL helmet. There is little evidence of load distribution by the suspension padding material and severe concentration of force to the skull is reduced only by the stiffness of the helmet shell itself. This is pointed out by the data in Figures 15 through 19, where the strain reading goes off the chart and damage of the instrumented head shell was encountered during the comparative tests.

P-3, P-4 Helmet

The P-3, P-4 helmet suspension system is reasonably flexible and distributes the load during top helmet blows until "bottoming" occurs. Side blows are resisted by the ear pads and rear blows are taken by the helmet shell edge directly against the neck. Very little resistance is provided against frontal blows. Because of the flexible suspension, accelerations were low until "bottoming" occurred. This same flexibility permitted "bottoming" to occur at a comparatively low energy level, which greatly reduces the protective value of the helmet.

CVC Flight Helmet (CVC-CAL)

During the dynamic tests, the CVC Shell exhibited sufficient rigidity to provide better protection than the other two flight helmets. The crown geodetic suspension system has comparatively little stretch which produces moderately higher accelerations of the head during impact but increases the margin of safety against "bottoming". Blows were applied to the side, front, top, and back of the CVC Flight Helmet at higher impact levels than could be applied to the other two helmets within the criterion of protection. From the data obtained, all evidence indicated that the CVC-CAL provides protection superior to either of the other two flight helmets tested. Within the envelope of blows struck to the helmet, "bottoming" occurred for both the Gentexite and the P-3, P-4 helmets at comparatively low velocity level (13 ft./sec. with the 8.9-lb. striker). The CVC-CAL helmet did not "bottom" under blows of 18.3 ft./sec. with 8.9-lb. striker. Using the energy level to "bottom" as a criterion of protection, the CVC-CAL helmet would provide an improvement in protection against impact blows of over 96%.

Impact energy levels were increased for the CVC-CAL Helmet until it was demonstrated that its protective capabilities exceeded those of the two other flight helmets used for comparison. Testing was not extended for the CVC-CAL Helmet because of damage to the instrumented head-form.

In none of the tests did the accelerations of the head-form become excessive.

C. Discussion of Test Results

The comparative helmet data obtained during the helmet evaluation has been compiled and analyzed and the results presented in Figures 15 through 19. This data was obtained using the Helmet Impactor developed during an earlier phase of the program. It is important to note that the results presented should be considered only as a comparison even though the presentations are in terms of absolute values. The micro-inch per inch strains in the head shell are an index of distribution of strain but should not be construed as the strain that might be experienced in a human skull. Complexities of an indeterminate spherical shell, thickness of shell, modulus of elasticity, and stress characteristics prevent an absolute correlation with head injury potential. The Gentexite and the P-3, P-4 helmets were used for the comparative evaluation of the CVC-CAL helmet. In one instance, a football helmet with a suspension similar to the CVC-CAL helmet was tested in place of the Gentexite helmet which failed at a lower impact velocity.

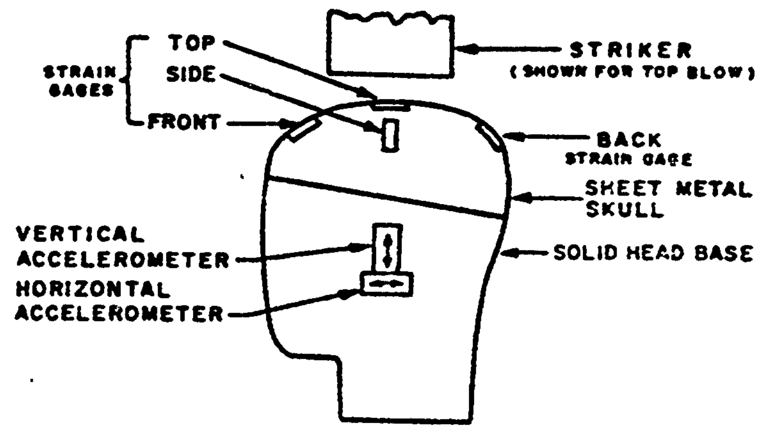
The magnitude and direction of the impact blow are shown at the top of each figure and the individual peak reading of the horizontal and vertical accelerometers as well as each strain gage has been presented in the bar graph data.

Initially, static and dynamic distribution tests were performed with the instrumented head form. Disks of felt and wood contour blocks were made to provide different areas of contact on the head-form to establish a relationship between strain gage reading and the distribution of the force over the head-form. The results of these tests were not conclusive. A relationship between area of contact and force was found to exist; however, this relationship changes appreciably when the forces or impact energies are varied. The only general conclusion reached was that the strain gage readings were lowered as distribution was increased for a given applied force or impact energy. Further, it was not possible to compare directly the effect of blows from different directions to the helmet. It is necessary to compare one helmet to another for the same impact energy and direction of blow. All impact blows were made directly over a strain gage to indicate "bottoming" of the helmet against the head-form and concentration of force. In the final analysis, this measurement was used as an index of the helmet's protective limit.

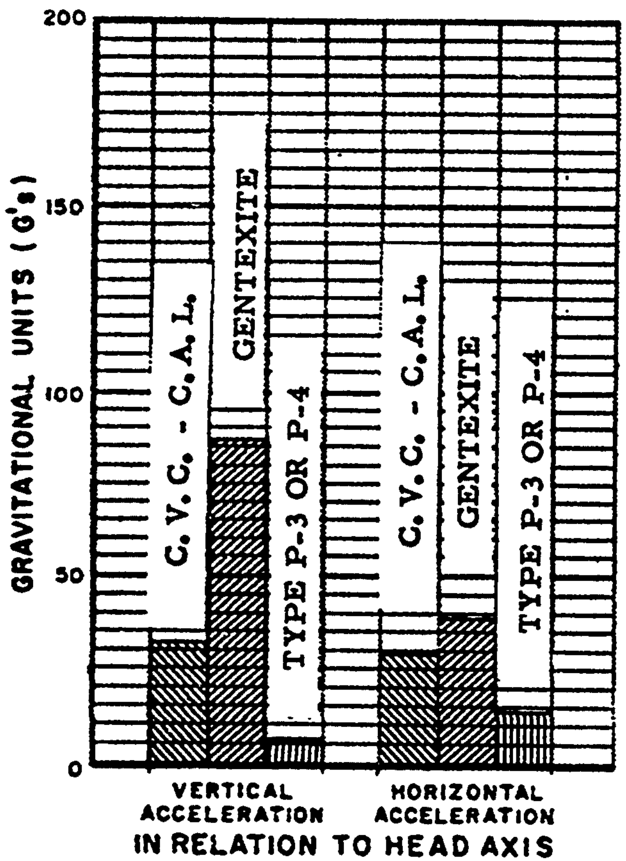
DYNAMIC HEAD IMPACT TEST RESULTS

USING HELMET IMPACTER
DEVELOPED DURING CONTRACT
No. DA19-129-QM-910

STRIKER WEIGHT 8.9 lb.
STRIKER SHAPE Flat - 4.5" dia.
STRIKER VELOCITY 14.4 ft./sec.
DIRECTION OF IMPACT Back - 45°



TEST HEAD FORM



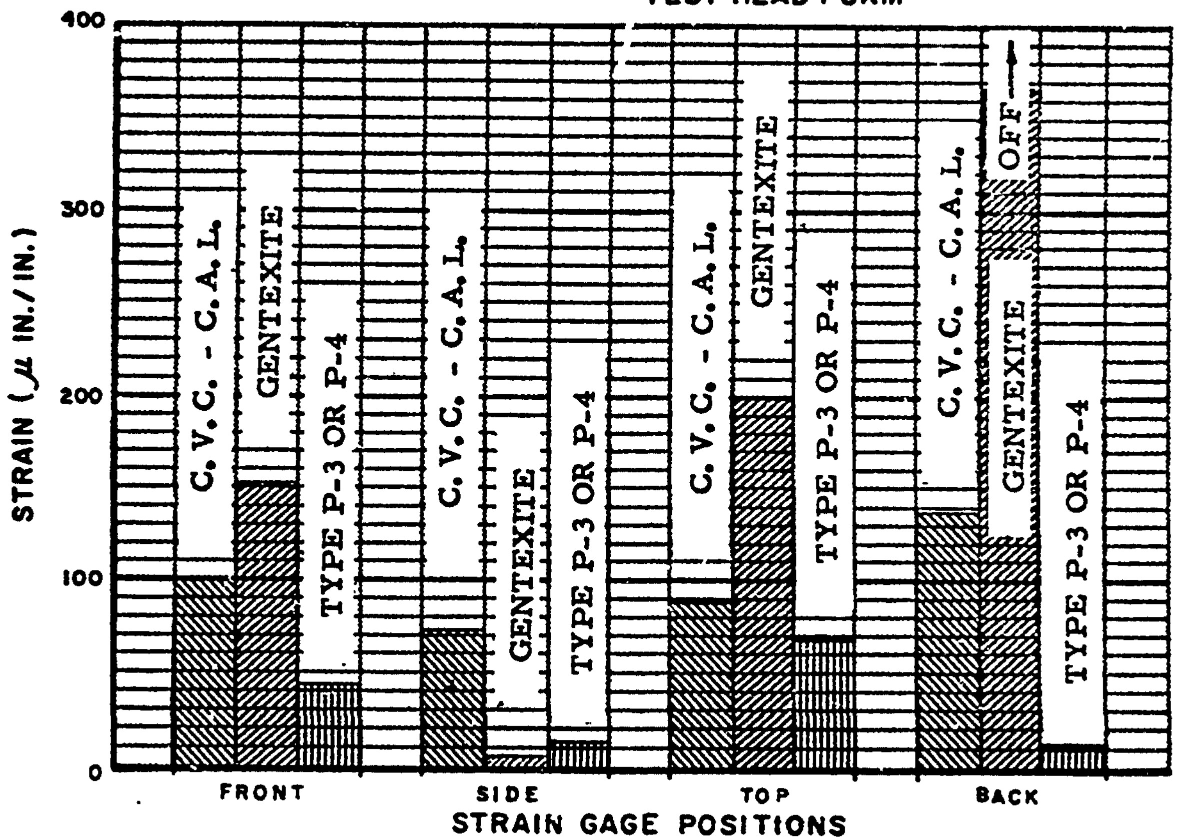
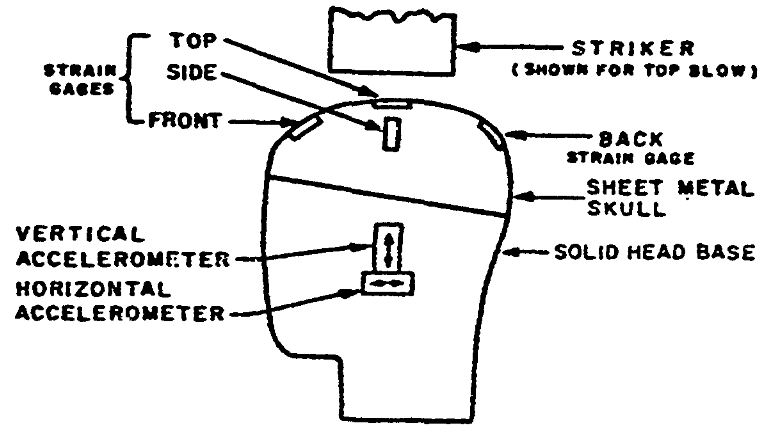


Figure 15

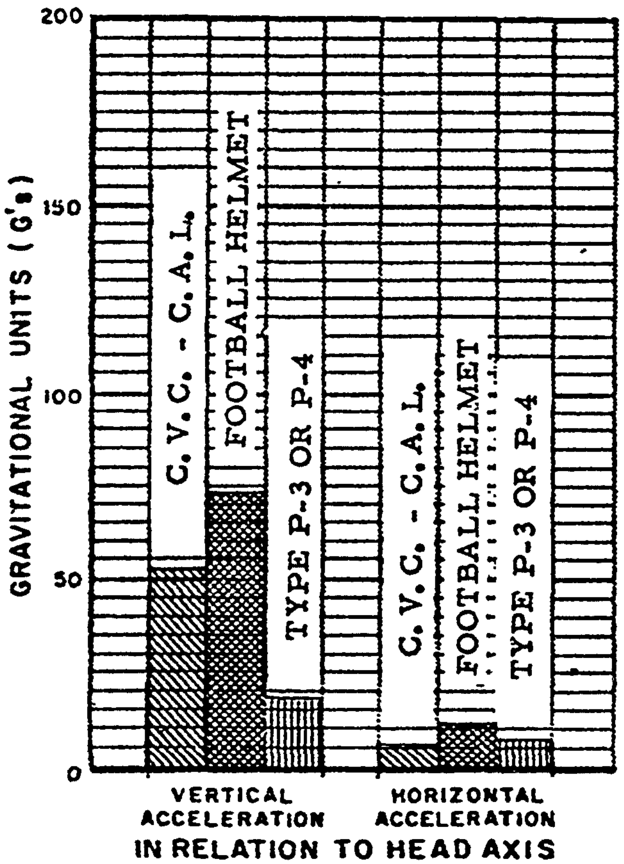
DYNAMIC HEAD IMPACT TEST RESULTS

USING HELMET IMPACTER DEVELOPED DURING CONTRACT No. DA19-129-QM-910

STRIKER WEIGHT 8.9 lb.
STRIKER SHAPE Flat - 4.5" dia.
STRIKER VELOCITY 16.4 ft./sec.
DIRECTION OF IMPACT Top



TEST HEAD FORM



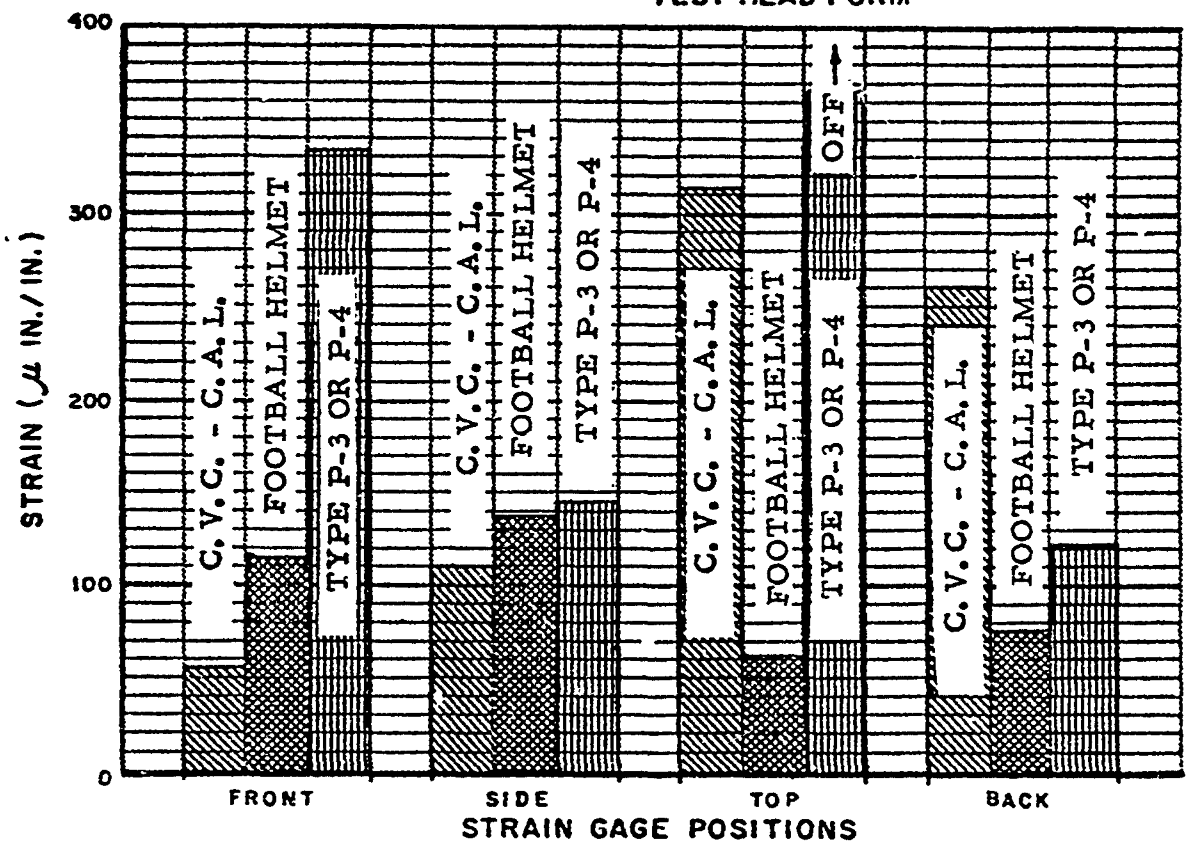


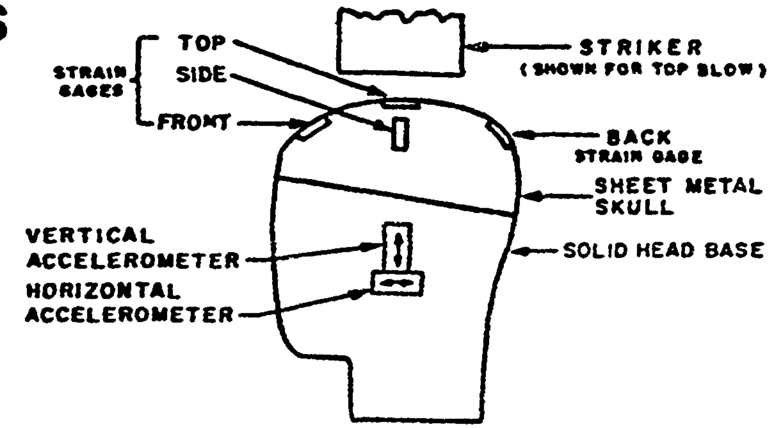
Figure 16

OG 1163-D-1

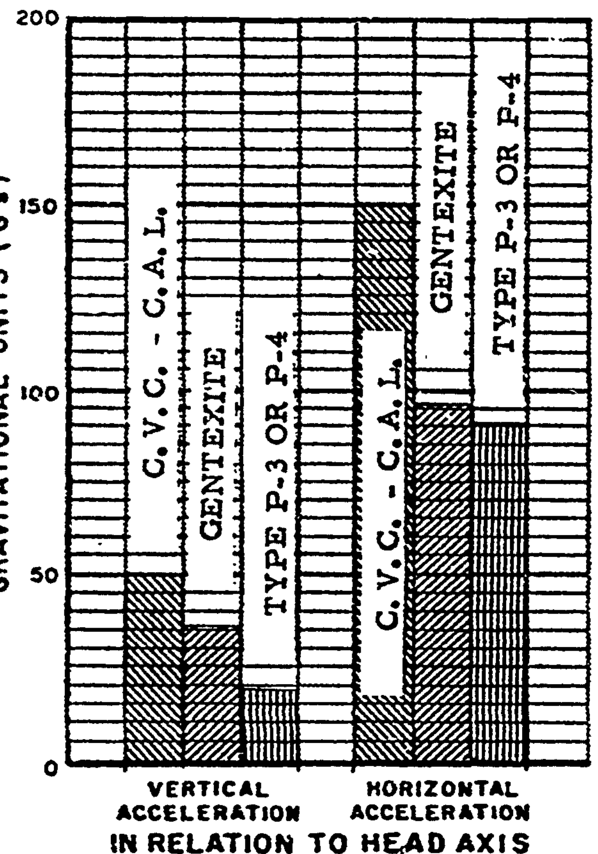
DYNAMIC HEAD IMPACT TEST RESULTS

USING HELMET IMPACTER DEVELOPED DURING CONTRACT No. DA19-129-QM-910

STRIKER WEIGHT 8.9 lb.
STRIKER SHAPE Flat - 4.5" dia.
STRIKER VELOCITY 18.3 ft./sec.
DIRECTION OF IMPACT side - 45°



TEST HEAD FORM



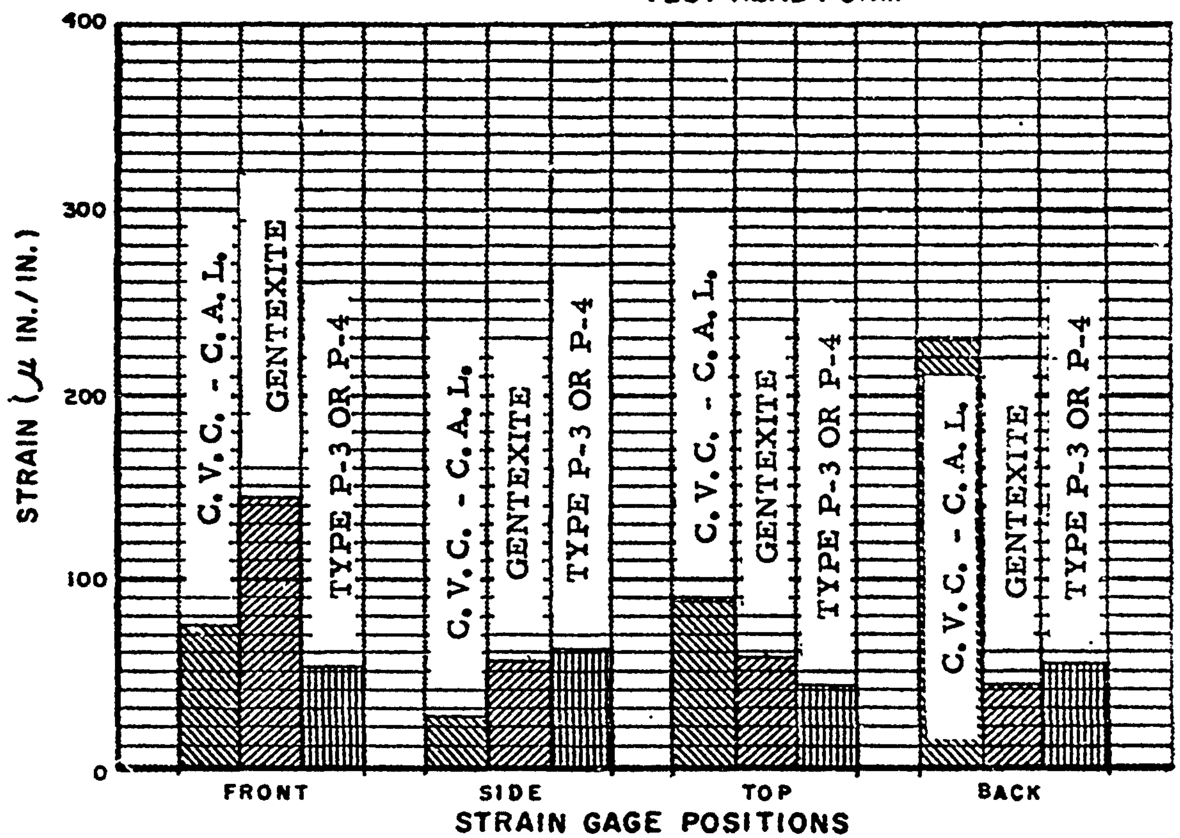


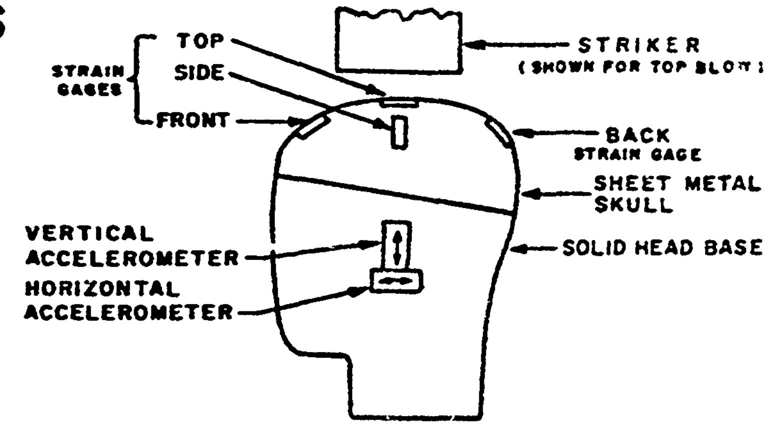
Figure 17

OG-1163-D-1

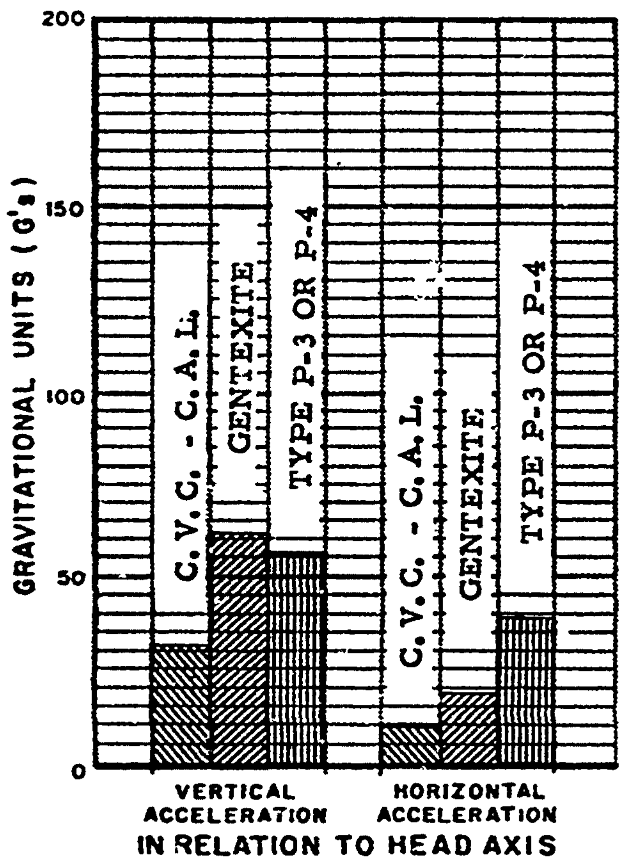
DYNAMIC HEAD IMPACT TEST RESULTS

USING HELMET IMPACTER DEVELOPED DURING CONTRACT No. DA19-129-QM-910

STRIKER WEIGHT 8.9 lb.
STRIKER SHAPE Flat - 4.5" dia.
STRIKER VELOCITY 13.0 ft./sec.
DIRECTION OF IMPACT Top



TEST HEAD FORM



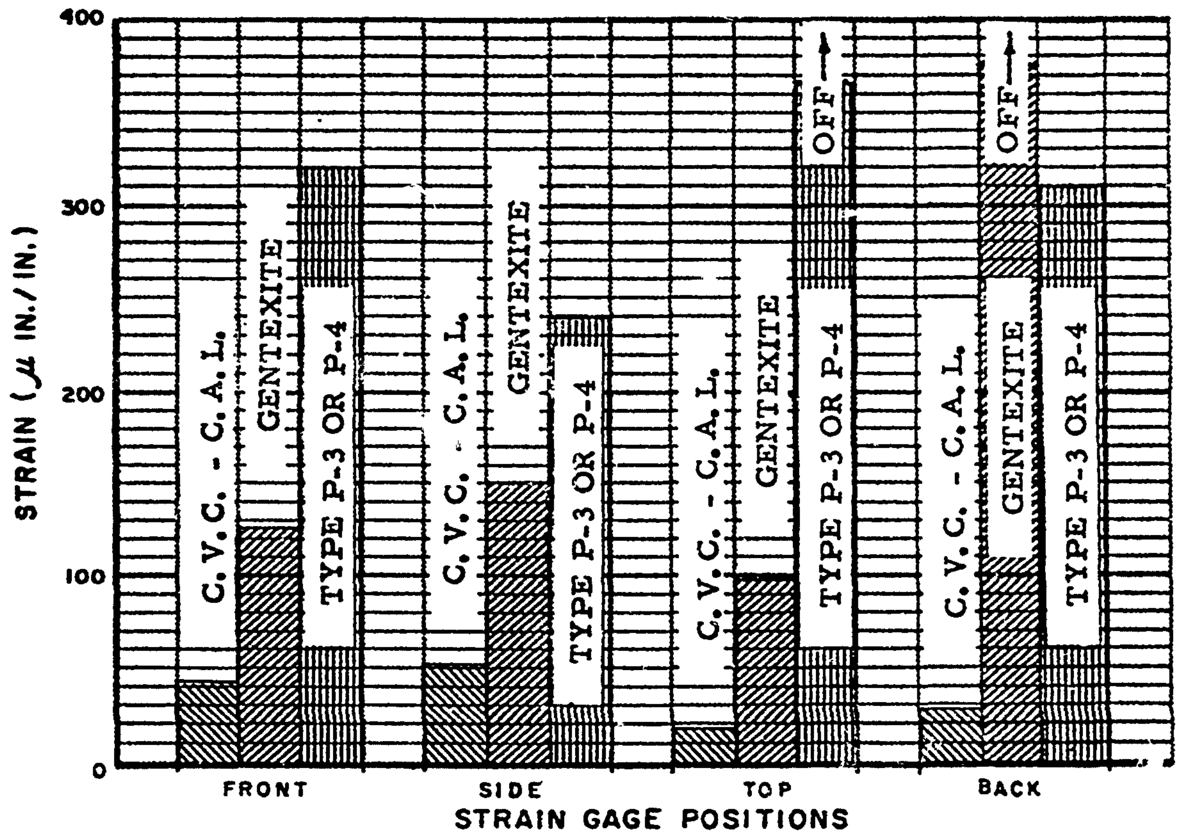
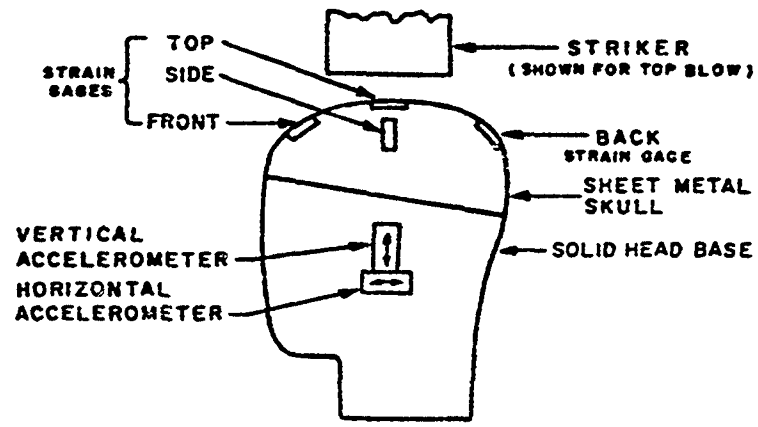


Figure 18

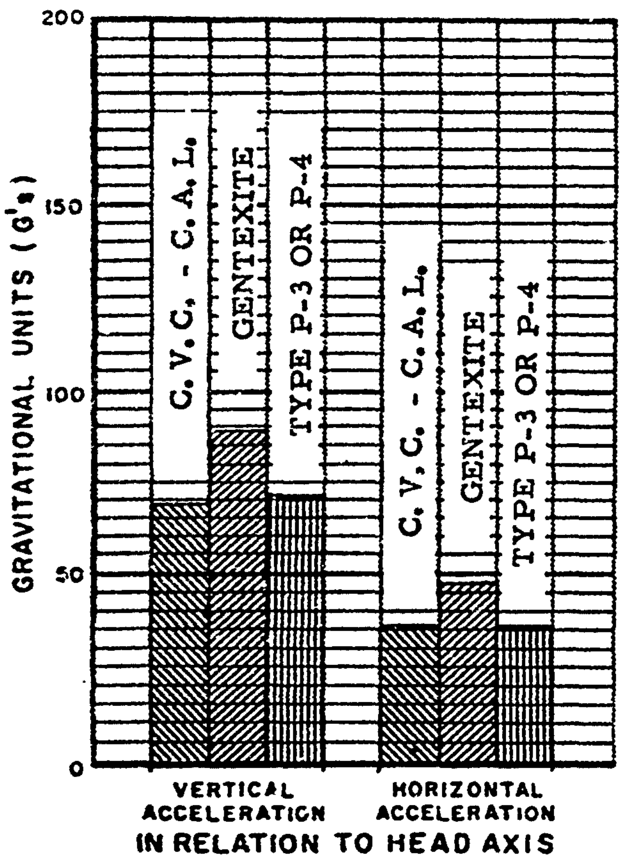
DYNAMIC HEAD IMPACT TEST RESULTS

USING HELMET IMPACTER DEVELOPED DURING CONTRACT No. DA19-129-QM-910

STRIKER WEIGHT 8.9 lb.
STRIKER SHAPE Flat - 4.5" dia.
STRIKER VELOCITY 14.4 ft./sec.
DIRECTION OF IMPACT Front - 45°



TEST HEAD FORM



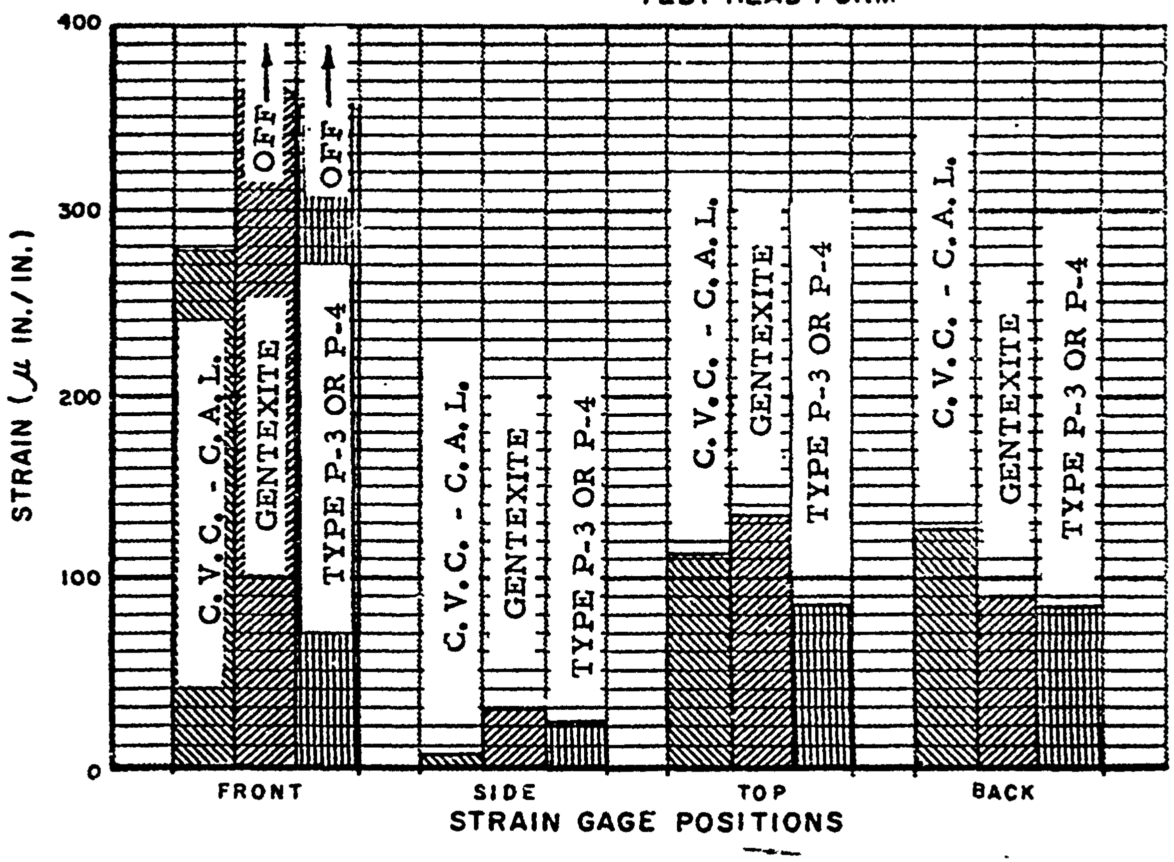


Figure 19

OG-1163-D-1

Several blows were applied to each helmet at gradually increasing increments of impact velocity. However, only the last or critical conditions have been compared on the bar graphs. It should be noted that in each instance where the strain readings are marked "OFF", the helmet "bottomed" and the head-form was dented sufficiently to require repair. It is for this reason that testing of the CVC-CAL Flight Helmet was continued only until assurance was obtained that the helmet had superior protective capabilities to the other flight helmets used for comparison.

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